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13. ABSTRACT (Maximum 200 words) They are in the process of completing two papers and four patents involving optical absorptions in GaAs which has led to the construction of a novel and highly sensitive optical temperature sensor. Another patent involving a liquid level sensor has become a by-product of the current research. They have studied two-photon optical pumping in semiconductors are continuing. Their attempts are focused on observing a number of new optical effects including nonlinear absorption and transmission phenomena, enhanced spontaneous and stimulated light scattering processes, etc. The construction of an external cavity semiconductor laser is completed. This will allow them to undertake a careful study of multiphoton optical pumping in semiconductors to generate IR radiation and a variety of studies involving narrow-gap semiconducting compounds outlined in their proposal. They have studied the feasibility of room temperature operation of a tunable coherent source involving multiple quantum well material. An invention disclosure has been filed with the U.S. Air Force Patent Office for work performed on multiple quantum well material under this contract. They have received the delivery of				
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two large laser systems along with a variety of test and measurement equipment to enhance the current research under this contract. They have already utilized these lasers to explore elementary excitation in optical thin film layers of semiconductors. They have completed the construction of a simple remote (non-contact) temperature sensor to directly measure heat buildup in semiconductor materials as a result of high power optical laser excitation, as proposed in Statement of Work F of our research proposal. Finally, an experiment involving four-photon mixing to probe electron dynamics in the Gunn effect regime in GaAs and HgCdTe superlattice, utilizing our two recently constructed tunable laser systems, is in the planning stage.

AFOUR. 89-1542

Semi-Annual Progress Report
on
NONLINEAR OPTICAL INTERACTIONS IN SEMICONDUCTORS

U.S. Air Force Contract #F49620-83-C-0147

February 10, 1984 to August 10, 1984

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ABSTRACT

We are in the process of completing two papers and four patents involving optical absorptions in GaAs which has led to the construction of a novel and highly sensitive optical temperature sensor. Another patent involving a liquid level sensor has become a by-product of the current research. We have studied two-photon optical pumping in narrow-gap semiconductors and our studies of multiphoton optical pumping in semiconductors are continuing. Our attempts are focused on observing a number of new optical effects including nonlinear absorption and transmission phenomena, enhanced spontaneous and stimulated light scattering processes, etc. The construction of an external cavity semiconductor laser is completed. This will allow us to undertake a careful study of multiphoton optical pumping in semiconductors to generate IR radiation and a variety of studies involving narrow-gap semiconducting compounds outlined in our proposal.

We have studied the feasibility of room temperature operation of a tunable coherent source involving multiple quantum well material. An invention disclosure has been filed with the U.S. Air Force Patent Office for work performed on multiple quantum well material under this contract.

We have received the delivery of two large laser systems along with a variety of test and measurement equipment to enhance the current research under this contract. We have already utilized these lasers to explore elementary excitation in optical thin film layers of semiconductors.

We have completed the construction of a simple remote (non-contact) temperature sensor to directly measure heat buildup in semiconductor materials as a result of high power optical laser excitation, as proposed in Part F of our research proposal.

Finally, an experiment involving four-photon scattering to probe electron dynamics in the Gunn effect regime in GaAeAs and HgCdTe superlattice, utilizing our two recently constructed tunable laser systems, is in the planning stage.

I. Research Objectives

The aim of this program is to investigate a variety of novel, nonlinear optical processes in semiconductors. These ideas will combine ultrafast spectroscopic techniques to probe the basic physics of the interaction of intense subpicosecond pulses with semiconductor systems. Ultimately, we hope to use these interactions as the basis for ultrafast/cw, tunable infrared sources. Among the processes we are studying, or plan to study, are the following:

- A. Multiphoton optical pumping in semiconductors to generate IR radiation, e.g., narrow-gap semiconducting compounds such as $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$.
- B. Generation of high-power coherent infrared (2μ with possible extension to 100μ) radiation using multiphoton pumping in external cavity, with narrow-gap semiconducting compounds.
- C. Infrared nonlinear optical processes in a traveling-wave ring cw laser of narrow-gap semiconducting compounds for generation of coherent infrared/submillimeter tunable radiation.
- D. Studies with a cw $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ laser in the infrared.
- E. Basic dynamics of electron-hole plasma in generating heat in semiconductor materials.
- F. Methods of preparing optical thin film layers by laser techniques to reduce chirp in picosecond pulses from IR semiconductor lasers.
- G. Electron-phonon relaxation time and coupling constants in semiconductors.
- H. Elementary excitations in polariton (electron-hole-photon) induced group-velocity dispersion in solids.

II. Accomplishments

Our studies of infrared nonlinear optical processes in a traveling-wave ring cw laser of narrow gap semiconducting compounds are continuing. During the past six months, we have succeeded in constructing a state-of-the-art ring cavity (Part 3 under Statement of Work). The advantage of our new configuration is that it can be operated at room temperature and with lower optical powers than existing semiconductor lasers. Furthermore, it can provide tunable output. We have recently made an invention disclosure to the U.S. Air Force for this novel system. The gain medium consists of an active media of multiple quantum well (MQW) material composed of approximately 100 Å layers of semiconductor to form many periods of a layered structure. The external cavity operation will allow mode-locked, pulsed or continuous operation and independent control of output power and frequency output.

Our invention provides several novel features: (1) It has a long shelf life and should not undergo thermal or photochemical degradation. (2) It is operable as a laser at room temperature as well as at temperatures above or below room temperature. (3) In contrast to dye lasers, there are no pressure or jet fluctuations. (4) By the use of a variety of semiconductors to form the multiple quantum well, we will not be restricted to those materials that can be formed as p-n junctions. The experimental work is still underway and a few papers providing detailed analysis of the research will be completed during the next few months.

Our studies of basic dynamics of electron-hole plasma in generating heat in semiconductor materials (Part 5 under Statement of Work) is continuing. To make a systematic measurement one needs a very sensitive temperature sensor. Recently, we have made an invention disclosure for a fiber optic temperature sensor which utilizes a semiconductor sample as a sensing media. Light is guided in an optical fiber to the semiconductor sample and back to the analyzing electronics. The band-gap energy of the semiconductor decreases with increasing temperature. Consequently, the absorption of light in the energy region of the band-gap changes with temperature. From the measured light absorption, the temperature of the semiconductor sample can be calculated. The above sensor can operate in an environment of changing high electric or magnetic field without being influenced by those environmental perturbations. A detailed analysis and description of the invention is summarized in the invention disclosure and in a paper which will soon be submitted for publication.

In another experiment we are planning to utilize these two lasers to study four-photon mixing to probe electron dynamics in the Gunn effect regime. Two such lasers at frequencies ω_1 and ω_2 , transverse to a superlattice structure, will induce an AC current in the electron gas and, more importantly, will modulate the electron energy at the difference frequency, $\omega_1 - \omega_2$. Under ordinary circumstances, such an energy (or temperature) modulation has relatively little effect. If, however, the sample is in a sizable DC field, so that some carriers have spilled from the central conduction band valley to subsidiary minima, a temperature modulation can have a large effect. In particular, it will alter the ratio of light to heavy mass carriers [assuming $(\omega_1 - \omega_2)$ is smaller than the intervalley scattering rate], creating a dielectric constant modulation which then gives rise to four-photon mixing.

III. Invention Disclosure

1. Semiconductor platelet-based fiber optic temperature sensor.
2. Optically pumped room temperature narrow-gap semiconductor laser using superlattice as a gain medium.
3. Fiber-coupler for use in a fiber optics transmission sensor, where the fibers that guide the light to the sensor and back are parallel.
4. Fiber optic temperature sensor that uses the absorption properties of a semiconductor.
5. Fiber optics liquid level sensor.
6. Tandem coupling mechanism (a new measurement configuration for fiber optic sensors to eliminate the influence of a change of the coupling factor of the fiber coupler on the measurement result).

IV. Personnel

1. Mr. Herbert E. Grier, Chairman of the Board
2. Dr. Michael M. Salour, Principal Investigator
3. Dr. James H. Bechtel, Senior Scientist
4. Dr. Gerhard Schoner, Postdoctoral Fellow
5. Mr. Martin Kull, Research Engineer
6. Mr. Joe Costa, Research Engineer
7. Mr. Tom S. Call, Mechanical/Design Engineer
8. Mrs. Joan I. Tukey, Contract Administrator/Chief Financial Officer
9. Mrs. Jeanine H. Vandenberg, Admin. Assistant to Principal Investigator
10. Mrs. Leslie Marshall, Administrative Assistant

Dr. James H. Bechtel is working very closely with the principal investigator on the performance and implementation of the current AFOSR program. Since joining TACAN Aerospace Corporation last year, Dr. Bechtel's effort has been centered on optical pumping in superlattice structure and two-photon excitation of narrow gap semiconductors.

Dr. Gerhard Schoner has been with TACAN Aerospace Corporation since August of 1983. He has been working with the principal investigator and has played an important role in the measurement of heat in bulk semiconductor material and in the invention of the fiber optic temperature sensor. Dr. Schoner has a Ph.D. in Physics from the University of Graz in Austria. For the past few years he has been a member of the technical staff at Siemens Research Laboratory of Optics in Munich, West Germany. He recently completed his one year of appointment in our laboratory and will join the faculty at the University of Graz.

Mr. Thomas S. Call, a mechanical/design engineer at TACAN Aerospace Corporation, will devote a portion of his time on this contract. Mr. Call holds a Bachelor's degree in Physics from Princeton University. He worked on his thesis under the direction of Professor William Happer, and has spent one year of his post-graduate studies in Japan.

Mr. Joe Costa, a research engineer at TACAN Aerospace Corporation, will continue his work on the optical design of the research. Mr. Costa holds a Bachelor of Science degree in Electrical Engineering from the California Institute of Technology.

Mrs. Joan I. Tukey, Chief Financial Officer at TACAN Aerospace Corporation, administers budget proposals and government contracts for the company. Mrs. Tukey holds a Bachelor degree from the University of Minnesota and a Master of Science degree in Accounting from Georgetown University, Washington D.C..

Mrs. Jeanine H. Vandenberg, Administrative Assistant to the Principal Investigator at TACAN Aerospace Corporation, manages all contract manuscripts, proposals and patents for the company. Mrs. Vandenberg completed most of her undergraduated studies in Business Administration at the University of Southern California, Los Angeles, holds a Bachelor degree from the University of California, Irvine, and is currently completing her MBA at National University, San Diego.

Mrs. Leslie Marshall, administrative assistant at TACAN Aerospace Corporation, provides the company with support in accounting, contract administration, and office management. Mrs. Marshall holds a Bachelor degree from California State University, Fullerton.

Mr. John M. Malloy, a management consultant in the areas of operations and contract administration, will continue to interface with TACAN Aerospace Corporation with respect to contract management. Mr. Malloy holds an MBA from Harvard Graduate School of Business Administration.

The accounting firm of Price-Waterhouse performs all internal audits for TACAN Aerospace Corporation.

V. Coupling

A. C.N.R.S., Physique du Solide et Energie Solaire

We have an on-going interaction with Dr. Christian Verie on the growth of high quality narrow-gap semiconductor crystals of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$. In the past, Dr. Verie has collaborated with the principal investigator on the growth of such crystals and we are currently discussing the possibility of a joint paper.

B. Dr. D.C. Reynolds, Wright-Patterson AFB, Ohio

Dr. Reynolds has provided us with a large, excellent quality CdS and GaAs crystal for use in nonlinear optic experiments. The principal investigator has visited Dr. Reynold's crystal growing facilities and we expect to increase our interaction in the future.

C. Professor N. Bloembergen, Harvard University

In the past, we have collaborated with Professor Bloembergen and his research group at Harvard University. Professor Bloembergen has visited our laboratory in La Jolla during the past year and we expect to perform another joint publication in the future.

D. Professor W. D. Laidig, North Carolina State University

We have an on-going interaction with Professor Laidig of North Carolina State University. We have visited his crystal growing facilities and the availability of an MBE machine in his laboratory has made possible a number of joint efforts currently underway at TACAN Aerospace Corporation. We regularly discuss optical pumping and four-wave parametric mixing in multiple quantum well material and plan to publish together.

E. TRW, Hughes Research Laboratory, Hewlett-Packard Research Laboratory

We have occasional contact with a number of scientists at TRW (Los Angeles), Hughes Research Laboratory (Malibu, CA) and Hewlett-Packard Research Laboratory (Palo Alto, CA). We have received a number of enquiries from many other laboratories (both from the government and industry) about the status of our optically pumped semiconductor laser and intracavity nonlinear optical techniques developed under our AFOSR contract. The principal investigator has given invited lectures at the above laboratories and a number of colloquium talks at various universities and government laboratories.

VI. Expansion in Facilities and Equipment

On April 1, 1984, TACAN Aerospace Corporation relocated its headquarters and laboratories to Carlsbad, California. This facility, located at 2111 Palomar Airport Road, Suite 100, contains laboratories which are specifically designed to accommodate a major expansion in our capital equipment pool. A number of large frame lasers, test measurement equipment, data processing systems, vibration free optical tables, crystal polishing facilities, fully equipped mechanical and electronic shops, etc. are part of this expansion. We feel this expansion and the specialized capital equipment purchased by TACAN Aerospace Corporation has provided a unique environment and a major enhancement to the productivity of our current research.